# Defense Technical Information Center Compilation Part Notice

## ADP022557

TITLE: Robust Design Algorithm for High-Frequency Traveling-Wave Tube Slow-Wave Circuits

DISTRIBUTION: Approved for public release, distribution unlimited

## This paper is part of the following report:

TITLE: 2006 IEEE International Vacuum Electronics Conference held jointly with 2006 IEEE International Vacuum Electron Sources Held in Monterey, California on April 25-27, 2006

To order the complete compilation report, use: ADA453924

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP022420 thru ADP022696

# Robust Design Algorithm for High-Frequency Traveling-Wave Tube Slow-Wave Circuits

**_Jeffrey D. Wilson_**
NASA Glenn Research Center
21000 Brookpark Rd., MS 54-5, Cleveland, OH, USA, 44135 (Jeffrey.D.Wilson@nasa.gov)

**_Christine T. Chevalier_**
Analex Corporation
21000 Brookpark Rd., MS GES-AOS, Cleveland, OH, USA, 44135

**Abstract:** *An optimization algorithm has been developed to provide robust designs for slow-wave circuits of high frequency traveling-wave tubes. A simulated statistical performance test of a robust design for a 94-GHz folded waveguide circuit shows significantly less sensitivity to dimensional tolerance variations.*

**Keywords:** traveling-wave tube; optimization; simulated annealing; robust design; algorithm.

## Introduction

In the frequency regime of 60-600 GHz, vacuum electronics amplifiers have tremendous potential for high data rate secure communications, surveillance, and remote sensing. However dimensional variations resulting from conventional micromachining techniques that are adequate for lower frequency operation can be relatively large enough to cause serious degradation and variation of performance at higher frequencies. When this is the case, conventional design optimization procedures provide non-robust designs and the actual amplifier performance can substantially under-perform the predicted design performance. Thus, a new optimization procedure was developed to provide robust designs for high performance millimeter-wave and terahertz communications amplifiers.

## Analysis

The effects of dimensional variations on the phase shift, interaction impedance, and attenuation of several traveling-wave tube (TWT) slow-wave circuits were investigated at a frequency of 94 GHz with the 3-D electromagnetic simulation software CST Microwave Studio (MWS) [1]. This sensitivity analysis determined that the folded waveguide (Figure 1) was the most robust circuit.

MWS was then used to design the folded waveguide geometry for optimal power gain and to determine the dependence of the phase shift, interaction impedance, and attenuation on the period length 'p'. This information is used for input into the NASA Coupled-Cavity TWT Code [2] which calculates the interaction between an electron beam and the RF wave traveling through an entire slow-wave circuit consisting of several hundred periods of folded waveguide.

After the cold-test information is input into the NASA TWT Code, optimization routines in the code determine the lengths of the periods in the circuit that produce the best RF efficiency performance. Previously algorithms based on simulated annealing have been developed to optimize RF efficiency at a single frequency [3] and over a frequency bandwidth [4]. In this project, we created and developed an algorithm based on simulated annealing to optimize RF efficiency while taking into account dimensional tolerances. The details of the new algorithm will be presented at the conference.

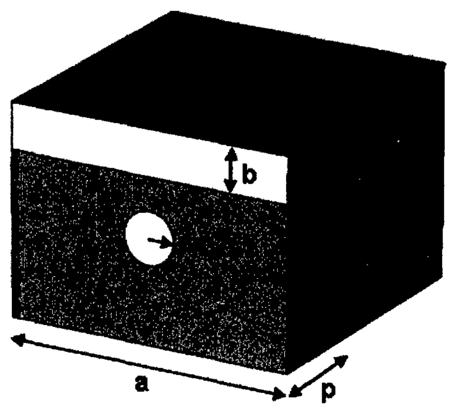


**Figure 1.** Folded-waveguide circuit geometry.

## Results

Two 94-GHz folded waveguide traveling-wave tube slow-wave circuits were designed, each with an input section, sever, and output section. The phase velocity taper in the first circuit was designed with the standard simulated annealing optimization algorithm [3]; the taper for the second circuit was designed with the new robust optimization algorithm.

In order to compare the designs, we performed Monte Carlo (MC) simulations consisting of 200 runs each on the standard and robust circuit designs. In practice, the lengths are generally either longer or shorter than the nominal values. Thus in the first MC simulation set, we assumed that the lengths had a pseudo Gaussian distribution centered at the nominal values plus half of the tolerance value. For each of the 200 MC runs, each individual cavity length of the slow-wave circuit is randomly assigned a value with

respect to the nominal value according to this probability distribution. In the second set of MC simulations, the probability distribution was assumed to be a pseudo Gaussian centered at the nominal values minus half of the tolerance value.

For the first set, the results of the MC simulations are very similar for the two designs with average efficiency values of 4.92% for the robust design and 5.12% for the standard design. However for the second set, the MC results which are shown in Figure 2 are dramatically different for the two designs. While the average efficiency value with the standard design is only 1.31%, it is 4.09% with the robust design. This represents an increase by a factor of 3.12. Thus the effect of the robust design is to broaden the 'sweet spot' around the nominal design values. Since we don't know a priori whether manufactured circuits will have period lengths either shorter or longer than the specified nominal lengths, the robust design is more likely to produce favorable performance.

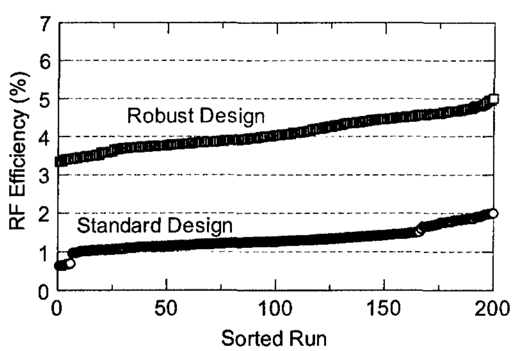


**Figure 2.** Distributions of RF efficiencies of robust and standard designs with Monte Carlo simulations for period lengths with average values shorter than nominal values.

## Conclusions

In this project, we have created and developed a design optimization algorithm for improving the RF power, RF efficiency, and robustness of high frequency vacuum electronic amplifiers while taking into account the sensitivity to dimensional variations. The algorithm was tested by using it to design a 94-GHz folded waveguide circuit. The simulated statistical performance of this design with regard to pseudorandom dimensional variations was determined and compared to that of a design optimized with a standard method. The results showed that the robust design is comparable to the standard design when the circuit period lengths are on average longer than the nominal values. However when the circuit period lengths are shorter, the robust design is far superior. This indicates that the robust optimization algorithm produces a design that is significantly less sensitive to dimensional tolerance variations. At higher frequencies with corresponding higher relative tolerances, we expect that the superiority of robust design performance will be even more significant.

## References


1. http://www.cst.de.
2. Wilson, J. D., "Revised NASA Axially Symmetric Ring Model for Coupled-Cavity Traveling-Wave Tubes," NASA Technical Paper 2675, Jan. 1987.
3. Wilson, J. D., "A Simulated Annealing Algorithm for Optimizing RF Power Efficiency in Coupled-Cavity Traveling-Wave Tubes," *IEEE Trans. Electron Devices*, Vol. 44, no. 12, pp. 2295-2299, Dec. 1997.
4. Wilson, J. D., "Design of High-Efficiency Wide-Bandwidth Coupled-Cavity Traveling-Wave Tube Phase Velocity Tapers with Simulated Annealing Algorithms," *IEEE Trans. Electron Devices*, Vol. 48, no. 1, pp. 95-100, Jan. 2001.